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Feed Chute Geometry for Minimum Belt Wear

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Summary This paper is concerned with the feeding and transfer of bulk solids in conveyor belt operation. The paper focuses on chute design where the objective is to prevent spillage and minimise both chute and belt wear. It is shown that these objectives may be met through correct dynamic design of the chute and by directing the flow of bulk solids onto the belt at an acceptable incidence angle. The aim is to match the tangential velocity component of the feed velocity as close as possible to the belt velocity. At the same time, it is necessary to limit the impact pressure due to the change in momentum of the bulk solid as it feeds onto the belt.

1. INTRODUCTION

The efficient operation of belt conveyors depends on many factors, not the least of which are the effective loading or feeding of bulk solids onto the belts at the feed or intake end and the efficient transfer of bulk solids from one conveyor to another. In the case of feeding from belt or apron feeders, the fact that such feeders are normally limited to speeds of up to 0.5 m/s, the bulk solid has to be accelerated to enter the conveyor belt at a speed matching, as close as possible, that of the belt. Two methods of achieving this are possible

- the use of accelerator belts
- employing gravity to accelerate the bulk solid in association with a feed chute

Accelerator belts are the more costly of the above two methods and are subject to significant belt wear. Gravity feed chutes, which require the necessary head room to accelerate the bulk solid to belt speed, are the better option.

In the case of transfer points, the task of matching the bulk solid speed with that of the belt is usually made easier in view of the momentum of the bulk solid discharging from the first conveyor. However, very often transfers involve a change in direction and this requires particular attention being given to the chute design.

The objectives of chute design are to ensure streamlined flow without spillage and with minimum chute and belt wear. This, in turn, requires the correct choice of lining materials to suit the bulk solid and chute geometry.

2. FEEDING OR LOADING CONVEYOR BELTS

The case of loading a bulk solid onto a belt conveyor is now discussed. Relevant aspects of chute design are reviewed

2.1 Free Fall of Bulk Solid

Figure 1 illustrates the application of a gravity feed chute to direct the discharge from a belt or apron feeder to a conveyor belt. The bulk solid is assumed to fall vertically through a height 'h' before making contact with the curved section of the feed chute. Since, normally, the belt or apron speed $v_f \leq 0.5$ m/s, the velocity of impact v_i with the curved section of the feed chute will be, essentially, in the vertical direction.

For the free fall section, the velocity v_i may be estimated from

$$v_i = \sqrt{v_{fo}^2 + 2\,g\,h} \tag{1}$$

Equation (1) neglects air resistance, which in the case of a chute, is likely to be small. If air resistance is taken into account, the relationship between height of drop and velocity v_i (Figure 1) is,

$$h = \frac{v_\infty^2}{g} \log_e \left[\frac{1 - \frac{v_{fo}}{v_\infty}}{1 - \frac{v_i}{v_\infty}}\right] - \left(\frac{v_i - v_o}{g}\right) v_\infty \tag{2}$$

where v_∞ = terminal velocity

v_{fo} = vertical component of velocity of bulk solid discharging from feeder
v_i = velocity corresponding to drop height 'h' at point of impact with chute.

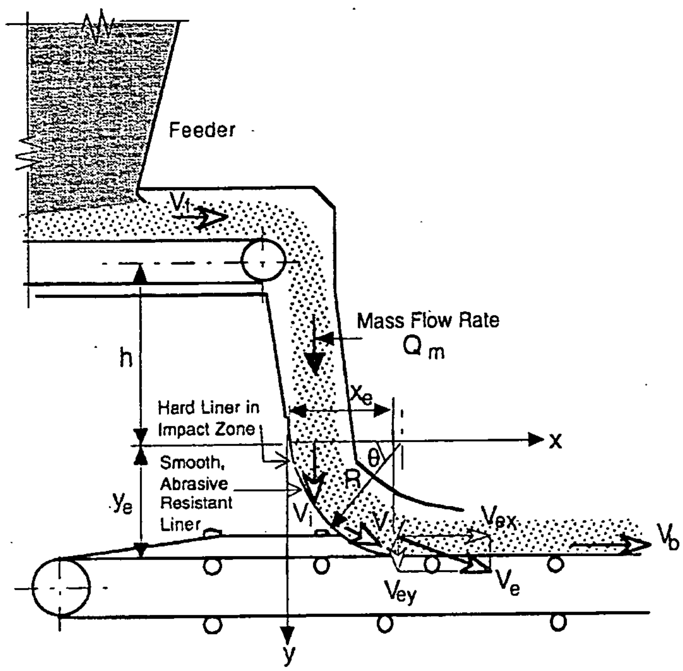

Figure 1. Feed Chute Configuration

2.2 Flow of Bulk Solid around Curved Chute

The flow around curved chutes, as depicted by the chute flow model of Figure 2, has been analysed in Ref[1].

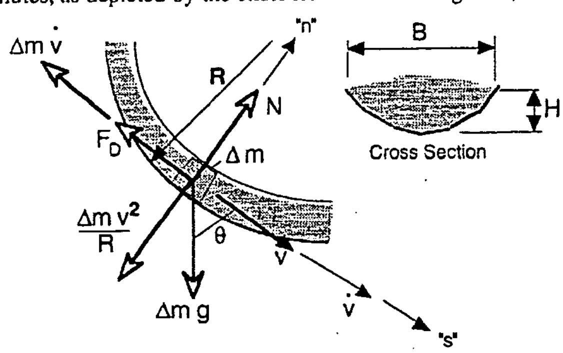

Figure 2. Chute Flow Model

The drag force F_D is due to Coulomb friction, that is

$$F_D = \mu_e N \tag{3}$$

where μ_e = equivalent friction which takes into account the friction coefficient between the bulk solid and the chute surface and the chute cross-section. μ_e is approximated by

$$\mu_e = \mu \left[1 + K_v \frac{H}{B}\right] \tag{4}$$

where μ = actual friction coefficient for bulk solid in contact with chute surface
K_v = pressure ratio. Normally K_v = 0.4 to 0.6.

Analysing the dynamic equilibrium conditions of Figure 2 leads to the following differential equation:

$$\frac{dv}{d\theta} + \mu_e v = \frac{g R}{v} (\cos\theta - \mu_e \sin\theta) \qquad (5)$$

If the curved section of the chute is of constant radius R, it may be shown that the solution of equation (5) leads to the equation below for the velocity at any location θ (Ref.[1]).

$$v = \sqrt{\frac{2 g R}{4 \mu_e^2 + 1} [\sin\theta (1 - 2 \mu_e^2) + 3 \mu_e \cos\theta] + e^{-2\mu_e\theta} [v_i^2 - \frac{6 \mu_e R g}{4 \mu_e^2 + 1}]} \qquad (6)$$

3. WEAR OF BELT AT FEED POINT

The objectives are

- to match the horizontal component of the exit velocity v_{ex} as close as possible to the belt speed
- to reduce the vertical component of the exit velocity v_{ey} so that abrasive wear due to impact may be kept within acceptable limits.

The abrasive wear of the belt may be estimated as follows:

Impact pressure $p_{vi} = \rho v_{ey}^2$ (kPa)

where ρ = bulk density, t/m³ v_{ey} = vertical component of the exit velocity, m/s

Abrasive wear factor $W_a = \mu_b \rho v_{ey}^2 (v_b - v_{ex})$ (kPa m/s) (7)

Where μ_b = friction coefficient between the bulk solid and conveyor belt v_b = belt speed

Apart from minimising belt wear, it is also important to minimise the wear of the chute lining surfaces. As illustrated in Figure 1, the curved chute is divided into two zones, the impact region where the low impact angles require the use of a hard lining surface, and the other, the streamlined flow region where low friction and low abrasive wear are a necessity.

4. LOADING A CONVEYOR BELT - AN EXAMPLE

The following example is considered: Referring to Figure 1, Q_m = 1000 t/h, h = 1.0 m, R = 3.0 m, ρ = 1 t/m³. It is assumed that $\mu_e = 0.5$

Based on a terminal velocity v_∞ = 30 m/s and zero initial velocity, $v_{fo} = 0$, the impact velocity is estimated to be, v_i = 4.4 m/s. Utilising equation (6), the variation in velocity 'v' around the chute may be computed as well as the velocity components v_{ex} and v_{ey}. These velocities are plotted, together with the chute profile in Figure 3. The maximum velocities are

$$v_{max} = 5.56 \text{ m/s at } \theta = 40^\circ$$
$$v_{x,max} = 4.43 \text{ m/s at } \theta = 60^\circ$$
$$v_{y,max} = 5.06 \text{ m/s at } \theta = 20^\circ$$

Of particular interest is $v_{ex} = v_{x,max}$ = 4.43 m/s for θ = 60°, the corresponding values of x and y being x_e = 1.5 m and y_e = 2.6 m. The total height of drop = h + y_e = 3.6 m

Also, the corresponding value of $v_y = v_{ey}$ = 2.56 m/s.
Assuming the belt speed is v_b = 4.5 m/s and μ_b = 0.6

From equation (4), the abrasive wear factor $W_a = 0.6 \times 1.0 \times 2.56^2 \times (4.5 - 4.43)$ = 0.28 kPa m/s. Note that it is not necessary to choose the condition for maximum v_{ex}. Lower values of W_a may be obtained by choosing other combinations of v_{ex} and v_{ey}.

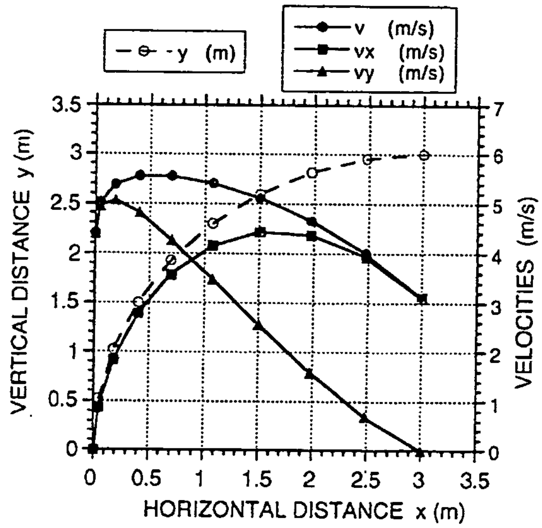

Figure 3. Curved Chute Performance
R = 3 m; v_i = 4.4 m/s ; μ_e = 0.5; Q_m= 1000 t/h; ρ = 1 t/m^3

It needs to be noted that, for a given head height, best performance is generally obtained by selecting a large radius 'R' relative to the height 'h'.

4. TRANSFER CHUTE DESIGN

Figure 4 illustrates a conveyor transfer in which the use of curved impact plates is employed. The lining is divided into two zones, one for the impact region under low impact angles, and the other for the streamlined flow. The concept of removable impact plates, used in conjunction with spares allows ready maintenance of the liners to be carried out without interrupting the production.

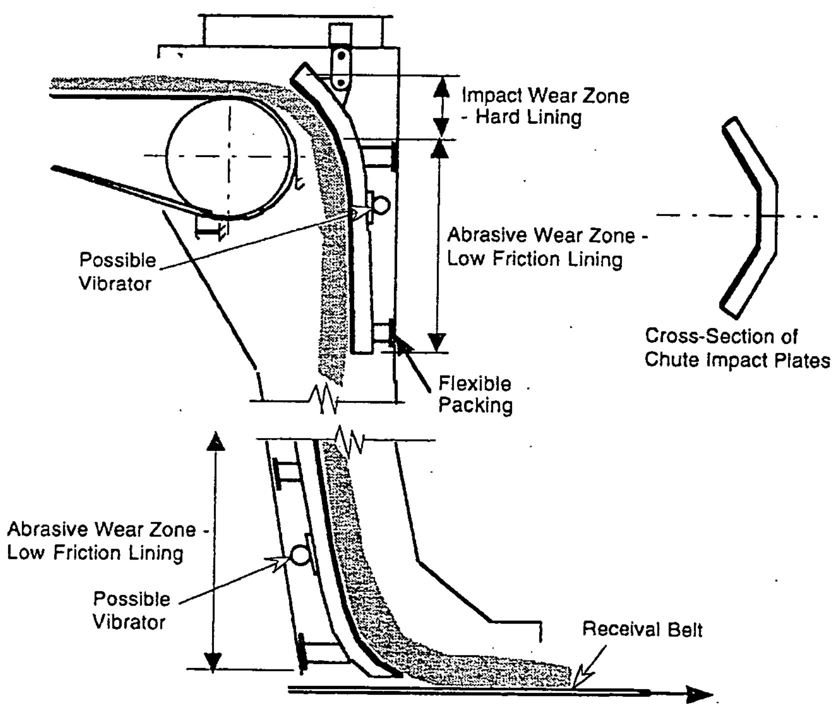

Figure 4. Transfer Chute Showing Impact Plates

The design of transfer chutes follows the procedures which have been well established. The method outlined in Section 2.2 for curved chutes may be readily adapted to inverted curved chute section as illustrated in Figure 5.

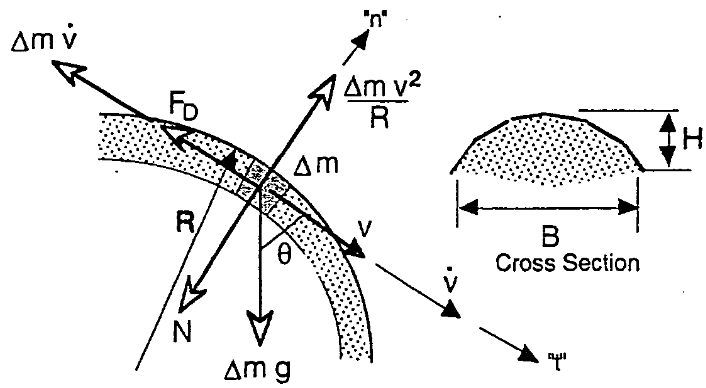

Figure 5. Inverted Curved Chute Model

Noting that $F_D = \mu_c N$, it may be shown that the differential equation is given by

$$\frac{dv}{d\theta} + \mu_e v = \frac{g R}{v} (\cos\theta + \mu_e \sin\theta) \qquad (8)$$

The solution of equation (8) is

$$v = \sqrt{\frac{2 g R}{4 \mu_e^2 + 1} [\sin\theta (1 - 2 \mu_e^2) + \mu_e \cos\theta] + e^{-2\mu_e\theta} [v_i^2 - \frac{2 \mu_e R g}{4 \mu_c^2 + 1}]} \qquad (9)$$

Equation (9) applies during positive contact. That is when

$$\frac{v^2}{R} \geq g \sin\theta \qquad (10)$$

5 CONVEYOR BELT WEAR TESTS

The abrasive wear of conveyor belt samples may be determined using the wear test apparatus illustrated in Figure 6. (Ref.[2]).

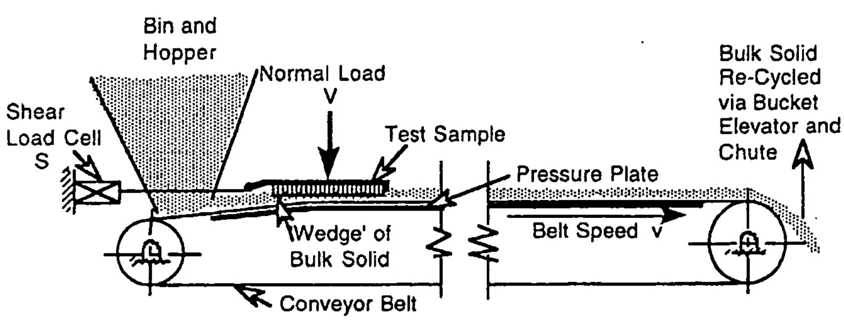

Figure 6. Wear Test Apparatus

As illustrated, the rig incorporates a surge bin to contain the bulk material, which feeds onto a belt conveyor. The belt delivers a continuous supply of the bulk material at a required velocity to the sample of material to be tested, which is held in position by a retaining bracket secured to load cells that monitor the shear load. The bulk material is drawn under the sample to a depth of several millimetres by the wedge action of the inclined

belt. The required normal load is applied by weights on top of the sample holding bracket. The bulk material is cycled back to the surge bin via a bucket elevator and chute. The apparatus is left to run for extended periods interrupted at intervals to allow measurement of the test sample's weight and surface roughness if required. The measured weight loss is then converted to loss in thickness using the relationship given in equation (11).

$$\text{Thickness Loss} = \frac{M.10^3}{A\,\rho} \quad \mu m \tag{11}$$

where M = Mass loss (g)
A = Contact Surface Area (m^2)
ρ = Test Sample Density (kg/m^3)

Tests have been conducted on samples of solid woven PVC conveyor belt using black coal as the abrading agent. A typical test result for a normal pressure of 2 kPa and a velocity of 0.285m/s is given in Figure 7. The graph indicates a wear rate of approximately 1.3 μm/hour. This information may be used to estimate the wear expected to take place due to loading of coal on this type of conveyor belt.

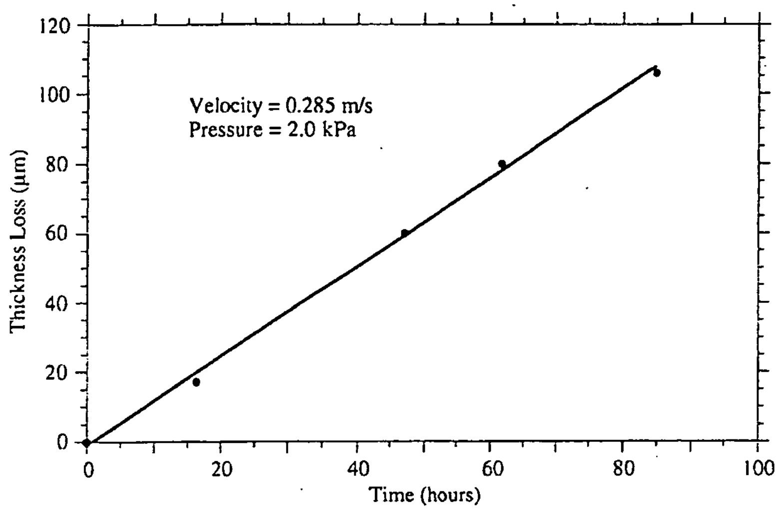

Figure 7 Wear Test Results

Referring to the example given in Section 4, the impact pressure $p_{vi} = \rho\, v_{ey}^2$ = 6.55 kPa and the relative velocity between the coal and the belt $v_b - v_{ex}$ = 0.07m/s. It has been shown (Ref.[2]) that abrasive wear is directly related to velocity and pressure. Using this, it is possible to estimate the wear that would take place at the loading point. It is assumed that the average differential velocity in the acceleration zone is half the initial value:

Wear, Acceleration Zone W_{az} = 1.3 x (0.035 / 0.285) x (6.55 / 2.0) = 0.5 μm/hour

Knowing the entire belt length and the length of the acceleration zone, the wear expected for the conveyor belt may be estimated using the following relationship.

$$W_{ac} = W_{az} \frac{L_a}{L_b} \tag{12}$$

where L_a = Acceleration zone length
L_b = Total length of belt

$$L_b = (2 + C)\, L_c \tag{13}$$

where L_c = Centre-line length of conveyor

The factor C allows for belt take-ups and wrap around drive and end pulleys. Normally $C \leq 0.1$.

For a conveyor feed without skirtplates, the acceleration length is taken to be

$$L_a = \frac{(v_b^2 - v_{ex}^2)}{2\,\mu_b\,g} \geq 1.0 \qquad (14)$$

where μ_b = bulk solid and belt friction. Generally $\mu_b = 0.5$ to 0.7

For practical reasons, a lower limit of $L_a = 1.0$ m is recommended

Again referring to the previous example, the application of equation (14) gives $L_a = 0.053$ m, so that the value $L_a = 1.0$ is selected. If the total belt length is $L_b = 500$m, then the belt wear W_{ac} would be 1.0 μm per 1000 hours of operation or 5.0 μm per working year of, say, 5000 hours.

For the example considered, the influence of conveyor length on belt wear due to the loading at the feed point is illustrated in Figure 8. Once the conveyor length exceeds 200 m, the wear becomes very small as shown.

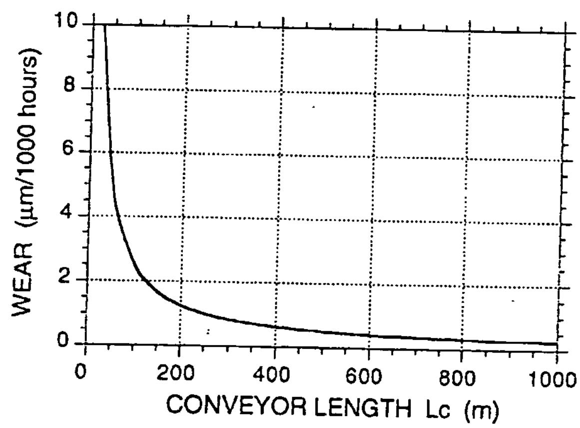

Figure 8. Wear as a Function of Conveyor Length

5. CONCLUDING REMARKS

This paper has been concerned with the feeding and transfer of bulk solids in conveyor belt operation. The paper has focused on chute design where the objective is to prevent spillage and minimise both chute and belt wear. It has been shown that these objectives may be met through correct dynamic design of the chute and by directing the flow of bulk solids onto the belt at an acceptable incidence angle. The aim is to match the tangential velocity component of the feed velocity as close as possible to the belt velocity. At the same time, it is necessary to limit the impact pressure due to the change in momentum of the bulk solid as it feeds onto the belt. Specifically the paper has covered the following topics:

- the dynamics of chute design including the examination of curved profiles for best performance
- the selection of design parameters to optimise the entry velocity onto the belt
- development of an impact/abrasive wear parameter for assessment of relative belt wear
- test procedures for abrasive wear of conveyor belts and prediction of absolute wear

6. REFERENCES

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2. Roberts, A.W. and Wiche, S.J., Prediction of Lining Wear Life of Bins and Chutes in Bulk Solids Handling Operations, Tribology International, Vol.26, No.5, pp. 345-351, (1993).